Crooked Lake Monitoring Study

STEUBEN COUNTY, INDIANA

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Prepared for:

Crooked Lake Association
c/o Keith Hoskins
801 W. Coliseum Boulevard
Fort Wayne, Indiana 46808

Prepared by:

JFNew

c/o Sara Peel, Project Manager
708 Roosevelt Road
Walkerton, Indiana 46574
574-586-3400

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CROOKED LAKE MONITORING STUDY
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1.0 DESCRIPTION OF THE STUDY AREA

1.1 Location

The Crooked Lake Watershed (14-digit hydrologic unit code 0405001090040) encompasses 7,512 acres (3,040 ha) in central Steuben County, Indiana (Figures 1 and 2). The watershed is part of the St. Joseph River Basin, which conducts water to Lake Michigan. Three drainages, Carpenter Drain, Palfreyman Drain, and the Loon Lake Tributary, transport runoff water from the watershed to Crooked Lake (Figure 3). Carpenter Drain is the largest of the three tributaries which originates in the northwestern portion of the City of Angola draining 1,987 acres (804 ha); Palfreyman Drain originates in the northeastern portion of the city and drains a total of 1,765 acres (714 ha). The Loon Lake Tributary drains 1,021 acres (413 ha) while about 2,739 acres (1,108 ha) of land drains directly to Crooked Lake. Water drains from the northwest corner of the third basin of Crooked Lake through an unnamed tributary to Lake Gage. After leaving Lake Gage, Lime Lake, and Tamarack Lake the tributary combines with Crooked Creek east of Orland. Crooked Creek in turn flows into the Fawn River, then into Pigeon Creek, before entering the St. Joseph River near Constantine, Michigan.

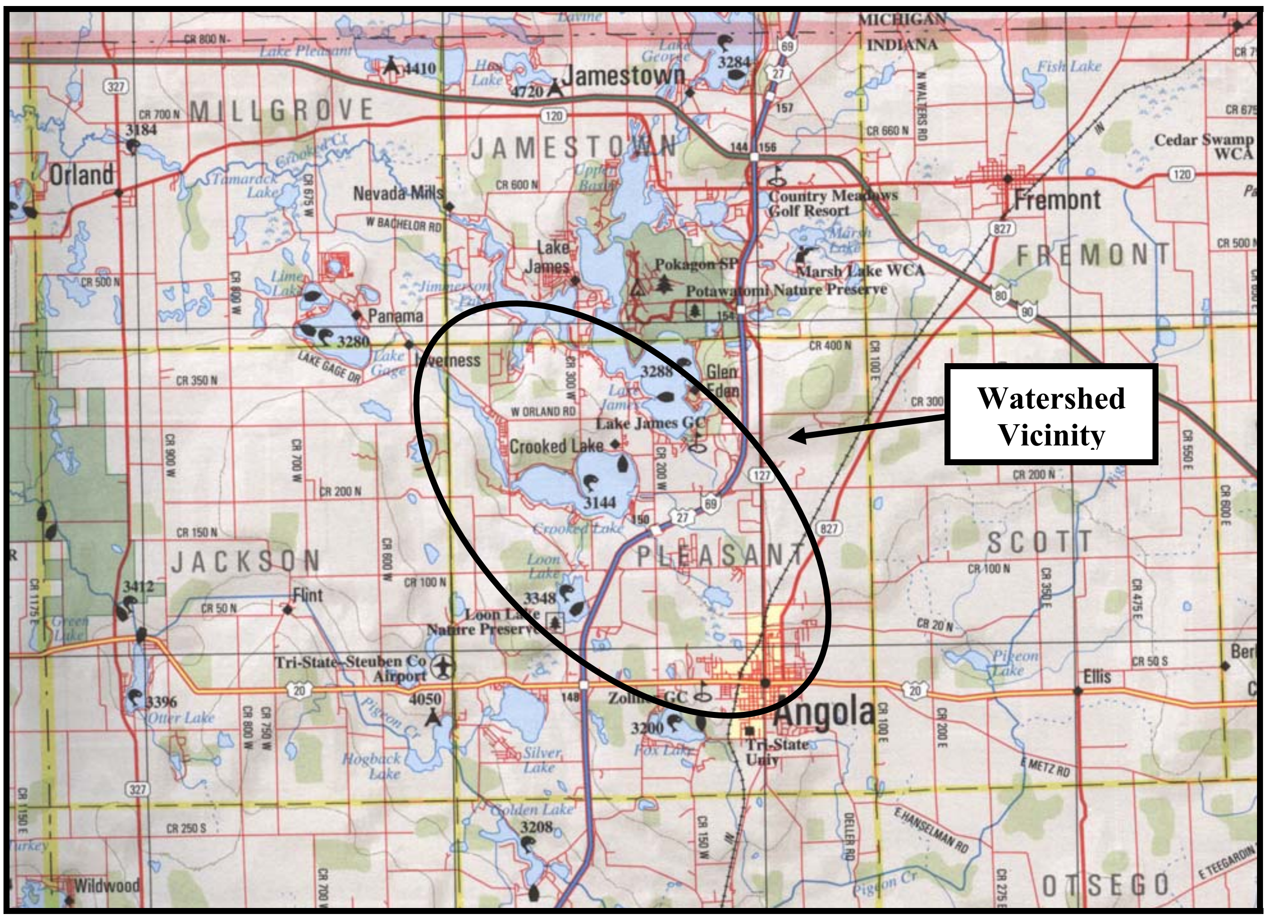

Figure 1. General location.

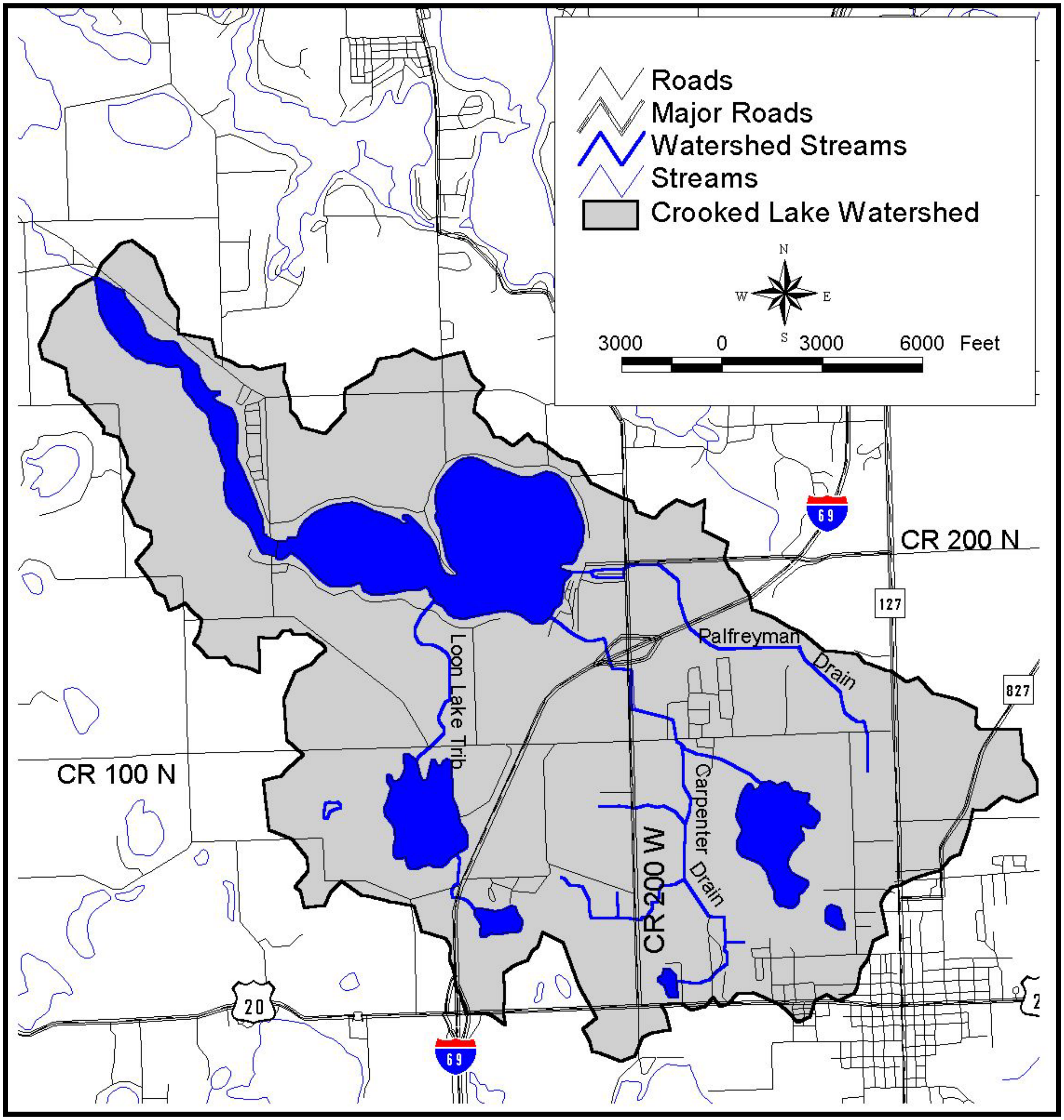

Figure 2. Crooked Lake Watershed.

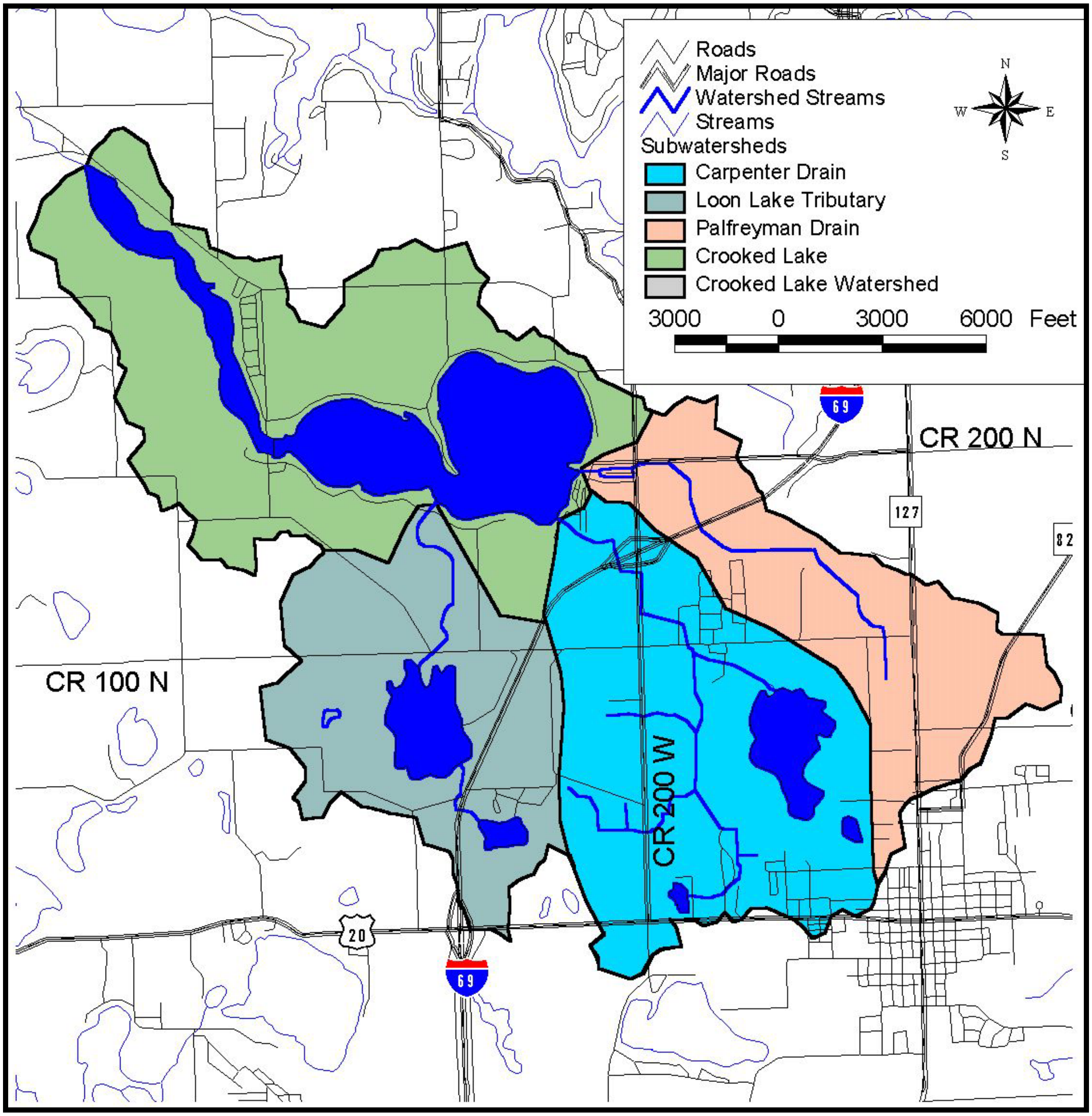

Figure 3. Crooked Lake subwatersheds.

1.2 Geologic History and Topography

Crooked Lake and its watershed formed during the most recent glacial retreat of the Pleistocene era. The advance and retreat of the Saginaw Lobe of a later Wisconsinan age glacier as well as the deposits left by the lobe shaped much of the landscape found in northeastern Indiana (Homoya et al., 1985). The Saginaw Lobe retreat left a broad, flat to rolling glaciated plain, which as been classified as the Northern Indiana Till Plain Ecoregion (Omernick and Gallant, 1988). Glacial fill and outwash, sandy gravelly beach ridges, flat belts of morainal hills, and bog kettle depressions characterize this ecoregion (Simon, 1997). The topography of the Crooked Lake Watershed is typical of much of Steuben County and reflects the geologic history described above. Land to the west of the lake exhibits a gently rolling topography. Relief changes from approximately 1050 feet above mean sea level at the highest point in the watershed to approximately 988 feet at the lake. Land to the east of the lake is flatter than land to the west of the lake with large wetland expanses draining through Carpenter Drain to the lake.

1. 3 Land Use

The Crooked Lake Watershed lies within the Northern Lakes Natural Area (Homoya et al., 1985). Natural communities found in this region prior to European settlement included bogs, fens, marshes, prairies, sedge meadows, swamps, seep springs, lakes, and deciduous forests. Like much of the landscape in Steuben County, a large portion of the Crooked Lake Watershed was converted to agricultural land uses. Today, about 54% of the watershed is utilized for agricultural purposes including row crop and pasture (Table 1; Figure 4). Corn and soybeans are the major crops grown on this land. An additional land use change has been residential development of much of the lake's shoreline and urban development along the Interstate 69 corridor and around the northern and northeastern edges of the City of Angola; consequently residential and commercial land use currently composes 7.6% of the total watershed acreage. Forests, wetlands, and open water account for approximately 38% of the total watershed.

Table 1. Land use in the Crooked Lake Watershed.

Land Use	Acreage	Percentage
Low Intensity Residential	225.1	3.0%
High Intensity Residential	32.5	0.4%
High Intensity Commercial/Industrial/Transport	314.3	4.2%
Urban Parkland	0.8	<0.1%
Deciduous Forest	1278.2	17.0%
Evergreen Forest	12.9	0.2%
Mixed Forest	2.6	<0.1%
Emergent Herbaceous Wetlands	306.4	4.1%
Woody Wetlands	296.7	3.9%
Open Water	1006.2	13.4%
Row Crops	2972.3	39.6%
Pasture/Hay	1063.4	14.2%
TOTAL	**7511.4**	**100.0%**

Source: USGS/EROS Indiana Land Cover Data Set, Version 98-12.

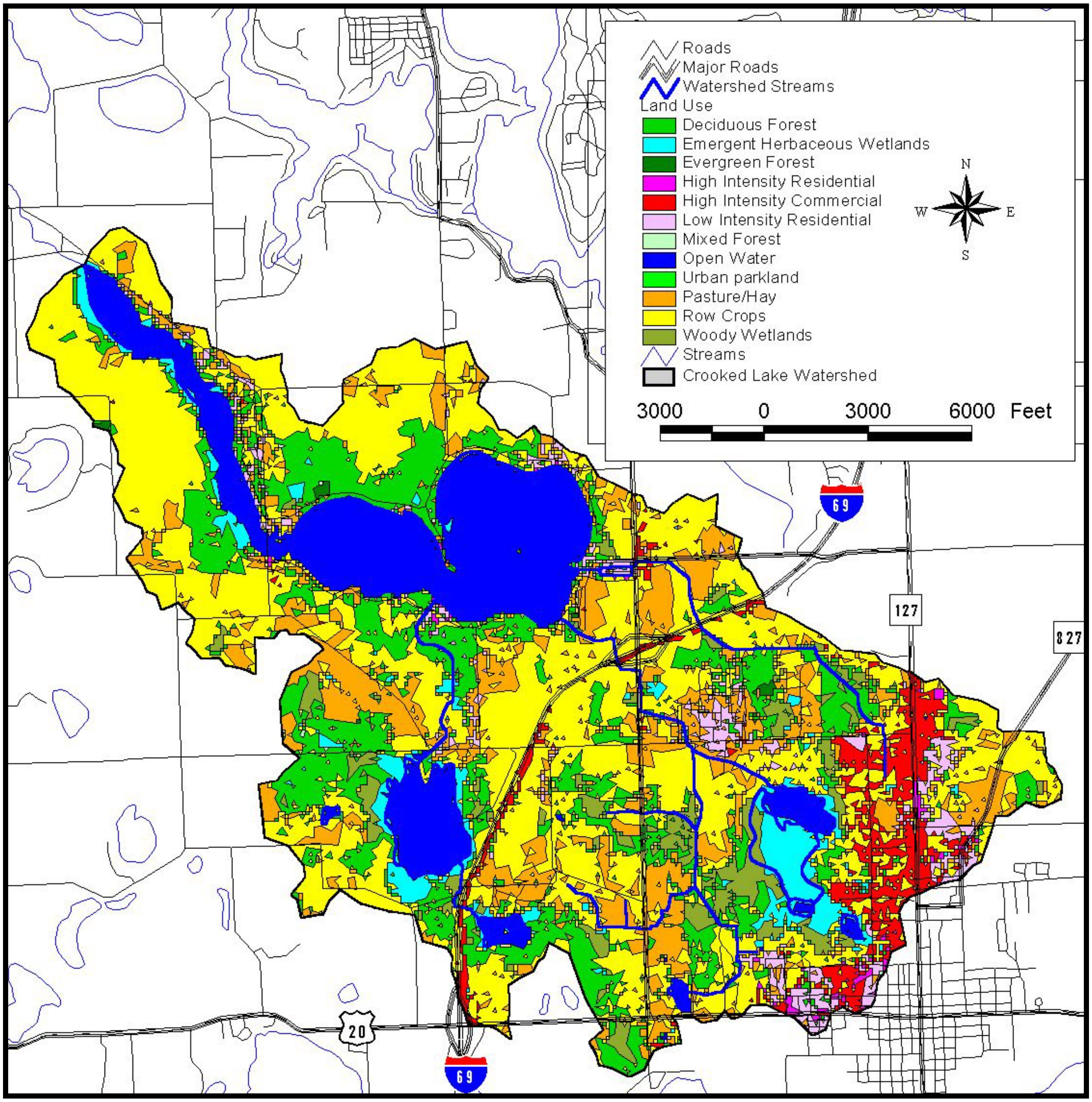

Figure 4. Land use in the Crooked Lake Watershed.

1.4 Soils

The soil types found in the Crooked Lake Watershed are a product of the original parent materials deposited by the glaciers that traversed the area 12,000 to 15,000 years ago. Soils that directly border the first and second basins of Crooked Lake and cover much of the Palfreyman Drain and Carpenter Drain Subwatersheds are of the Kosciusko-Ormas-Boyer Association, which is primarily composed of well-drained sand and gravel soils that formed on outwash plains and moraines. The Glynwood-Morley-Blount Association consisting of well-drained to poorly drained, silty soils covers much of the southeastern portion of the watershed located within the City of Angola. The Riddles-Miami-Brookston Association borders the third basin of Crooked Lake and occupies the Loon Lake Tributary Subwatershed. Soils of the Riddles-Miami-

Brookston Association are poorly drained, loamy soils which formed on till plains (Farmer, 1981).

1.5 Prior Studies

Table 2 lists prior studies conducted in the Crooked Lake Watershed. Most studies conducted in the area have been focused on documenting existing water or fishery conditions within the lake.

Table 2. Prior studies conducted in the Crooked Lake Watershed.

Year	Entity	Topic	Study
1967	IDNR, DFW	Fisheries	Lake Survey Report, Crooked Lake
1973-1977	SCLC/SCHD	Water Quality	Stream Water Quality Monitoring Program
1973	IDNR, DFW	Fisheries	Lake Survey Report, Crooked Lake
1975	USEPA	Water Quality	National Eutrophication Survey: Crooked Lake, Steuben County, Indiana, Working Paper No. 325
1979	IDNR, DFW	Fisheries	Lake Survey Report, Crooked Lake
1980	Purdue	Water Quality	Trophic Status of Fifteen Indiana Lakes in 1977
1981	USEPA	Wastewater Treatment	Environmental Impact Statement: Alternative Waste Treatment Systems for Rural Lake Projects, Case Study Number 4, Steuben Lakes Regional Waste District, Steuben County, Indiana
1986	IDEM	Water Quality	Indiana Lake Classification System and Management Plan
1987	IDNR, DFW	Fisheries	Lake Survey Report, Crooked Lake
1991	IDNR, DSC/ WWHA	Watershed Management	Crooked Lake: Watersheds of the Carpenter and Palfreyman Ditches Feasibility Study
1992	IDEM, CLP	Water Quality	Indiana Clean Lakes Assessment
1996-2002	IDEM, CLP/ CLA	Water Quality	Indiana Clean Lakes Volunteer Monitoring Program
1997	IDEM, CLP	Water Quality	Indiana Clean Lakes Assessment
1998	IDNR, DFW	Fisheries	Largemouth Bass Investigation
1998	IDNR, DSC	Water Quality	Wetland Construction, Palfreyman Drain
1999	IDNR, DSC/ CLA	Plant Community	Whole-Lake Experimental Plant Community Control
2001	IDNR, DFW	Fisheries	Assessment of Advanced Walleye Fingerling Stockings at Northern Indiana Lakes
2001	IDNR, DFW	Fisheries	Crooked Lake Fish Management Report
2002	IDEM, CLP	Water Quality	Indiana Clean Lakes Assessment
2003	CLA/JFNew	Watershed Management	Crooked Lake Monitoring Study

IDNR=Indiana Department of Natural Resources
DFW=Division of Fish and Wildlife
SCLC=Steuben County Lakes Council
SCHD=Steuben County Health Department
USEPA=U.S. Environmental Protection Agency
IDEM=Indiana Department of Environmental Management
DSC=Division of Soil Conservation
WWHA=William W. Hill and Associates, Inc.
CLP=Clean Lakes Program
CLA=Crooked Lake Association
Purdue=Purdue University, Department of Forestry and Natural Resources

2.0 STREAM WATER QUALITY INVESTIGATION

2.1 Historic Water Quality Assessment

Historic stream water chemistry studies have been conducted in the Crooked Lake Watershed by the Steuben County Health Department, William W. Hill and Associates, and Hoosier Riverwatch. The Steuben County Health Department assessed water quality in Carpenter and Palfreyman Drains from 1973 to 1977. William W. Hill and Associates collected water chemistry samples from both drains in 1987 and 1988. Hoosier Riverwatch volunteers collected water quality samples and assessed habitat in Carpenter Drain during 2001 and 2002.

2.1.1 Steuben County Health Department Study

The Steuben County Health Department sampled water quality at the mouths of Carpenter and Palfreyman Drains fifty-three times from 1973 to 1977. Both sites correspond to current sampling locations on each of the drains. As shown in Table 3, annual average total phosphorus concentrations ranged from 0.055 mg/l to 0.175 mg/l in Carpenter Drain and from 0.02 mg/l to 0.08 mg/l in Palfreyman Drain. Generally, Carpenter Drain possessed higher total phosphorus concentrations as measured by the Steuben County Health Department.

Table 3. Average total phosphorus concentrations measured by the Steuben County Health Department from 1973 to 1977.

Year	Carpenter Drain Mean Total Phosphorus Concentration	Palfreyman Drain Mean Total Phosphorus Concentration
1973	0.055 mg/l	0.02 mg/l
1974	0.175 mg/l	0.08 mg/l
1975	0.135 mg/l	0.04 mg/l
1976	0.135 mg/l	0.06 mg/l
1977	0.14 mg/l	0.06 mg/l

Source: William W. Hill and Associates, 1990.

2.1.2 William W. Hill and Associates Study

William W. Hill and Associates conducted inlet stream sampling during completion of the Crooked Lake Watershed Diagnostic Study. Sampling included collection of total phosphorus and total suspended solids samples from both Palfreyman and Carpenter Drains. Sampling sites utilized in the 1990 study correspond with sampling sites utilized during the current study. Generally, Carpenter Drain possessed slightly higher total phosphorus concentrations than those measured in Palfreyman Drain. However, total suspended solids concentrations measured in Palfreyman Drain exceeded those measured in Carpenter Drain (Table 4). The average total phosphorus concentration measured in Carpenter Drain during the 1988 sampling was 0.3 mg/l resulting in an average total phosphorus concentration by nearly 2.5 times the 1970s average. Likewise, total phosphorus concentrations measured in Palfreyman Drain in 1988 possessed an average of 0.235 mg/l or an increase of approximately 4.5 times the 1970s average (William W. Hill and Associates, 1990).

Table 4. Total phosphorus and total suspended solids concentrations measured at Palfreyman and Carpenter Drains during 1988.

Date	Carpenter Drain		Palfreyman Drain	
	TP (mg/l)	TSS (mg/l)	TP (mg/l)	TSS (mg/l)
5/23/88	0.60	78	0.60	96
6/16/88	0.30	43	0.24	83
7/14/88	0.15	--	0.15	--
7/20/88	0.18	--	0.33	--
8/5/88	0.63	32	0.23	54
8/15/88	--	--	0.01	--
8/19/88	--	--	0.12	--

Source: William W. Hill and Associates, 1990.

2.1.3 Hoosier Riverwatch Study

Hoosier Riverwatch volunteers sampled water chemistry in the Carpenter Drain on three occasions during 2001 and 2002. Participating volunteer groups measured seven different water quality parameters as described by the Hoosier Riverwatch guidelines (Hartman and Burk, 2000). Data for each parameter was assigned a quality value; a Water Quality Index (WQI) for the site was then calculated by summing the individual parameter values. Overall, Carpenter Drain water quality rated a WQI of good-excellent (Table 5). Carpenter Drain habitat was also scored on one occasion using the Citizens Qualitative Habitat Evaluation Index (CQHEI; Table 6). Generally, Carpenter Drain received high riparian area and stream shape scores; poor depth/velocity, riffle/run development, and subtrate generally limited habitat availability.

Table 5. Carpenter Drain water chemistry data and Water Quality Index (WQI) values gathered by Hoosier Riverwatch volunteers. A WQI score of 4 indicates excellent, 3 indicates good, 2 indicates fair, and 1 indicates poor water quality (Hartman and Burk, 2000).

Site	Date	Temp Δ (C)	% Sat	pH	Turb (NTU)	BOD (mg/l)	NO_3-N (mg/l)	OP (mg/l)	WQI
Carpenter Drain	6/13/01	0-2	91-110	6 or 8	0	0	0	2	3.71
	9/23/01	0-2	71-91	6 or 8	0	0	0	0-1	3.71
	7/26/02	0-2	91-110	6 or 8	0	0	0	0-1	3.86

Source: Hoosier Riverwatch database.

Table 6. Carpenter Drain habitat data and Citizens Qualitative Habitat Evaluation Index (CQHEI) values gathered by Hoosier Riverwatch volunteers. Maximum CQHEI is 110 points; quality ratings have not yet been developed (Hartman and Burk, 2000).

Location	Date	I	II	III	IV	V	VI	CQHEI
Maximum Possible Score		**24**	**20**	**20**	**20**	**11**	**15**	**110**
Carpenter Drain	6/13/02	15	12	15	15	1	8	66

Source: Hoosier Riverwatch Database.
I=Substrate (bottom type)
II=Fish cover (hiding places)
III=Stream shape and human alterations
IV=Stream forests and wetlands (riparian area) and erosion
V=Depth and velocity
VI=Riffles/runs

2.2 Current Water Quality Assessment

The water quality assessment portion of this study consisted of water chemistry sampling during base flow and during a storm water runoff event. Analysis of water quality parameters in inlet streams is important for understanding what is being introduced to the lake from its watershed. The data assists in guiding the prioritization of management actions and directing those actions toward the most critical areas.

2.2.1 Methods

Grab samples were collected from two of the three sampling sites in the Crooked Lake Watershed two times, lack of water in the Loon Lake Tributary during both base and storm flow prevented sample collection at this site (Table 7; Figure 5). The first sampling effort occurred on April 28, 2003 following a period of little precipitation. Less than 0.1 inches of rain fell in Steuben County in the week preceding sampling (Purdue Applied Meteorology Group, 2003). Base flow sampling provides an understanding of typical conditions in streams. The second sampling event occurred on May 1, 2003 following one day of rain. Local monitoring stations reported precipitation totals of approximately 0.75 to 1 inch in Steuben County (Purdue Applied Meteorology Group, 2003). Based on the precipitation, the May 1 sampling effort documented storm flow conditions in the watershed streams. Following storm events, the increased overland water flow results in increased erosion of soil and nutrients from the land. In addition, precipitation washes pollutants from hardscape in the watershed. Thus, stream concentrations of nutrients and sediment are typically higher following storm events. In essence, storm sampling presents a “worst case” picture of watershed pollutant loading.

Table 7. Detailed sampling location information for the Crooked Lake.

Site	Stream name	Road location	Place sampled
1	Loon Lake Tributary	Shady Side Drive	no sample collected due to lack of water in stream channel
2	Carpenter Drain	4-H Park entrance road	upstream of road crossing
3	Palfreyman Drain	CR 200 W and CR 200 N	upstream of CR 200 W crossing

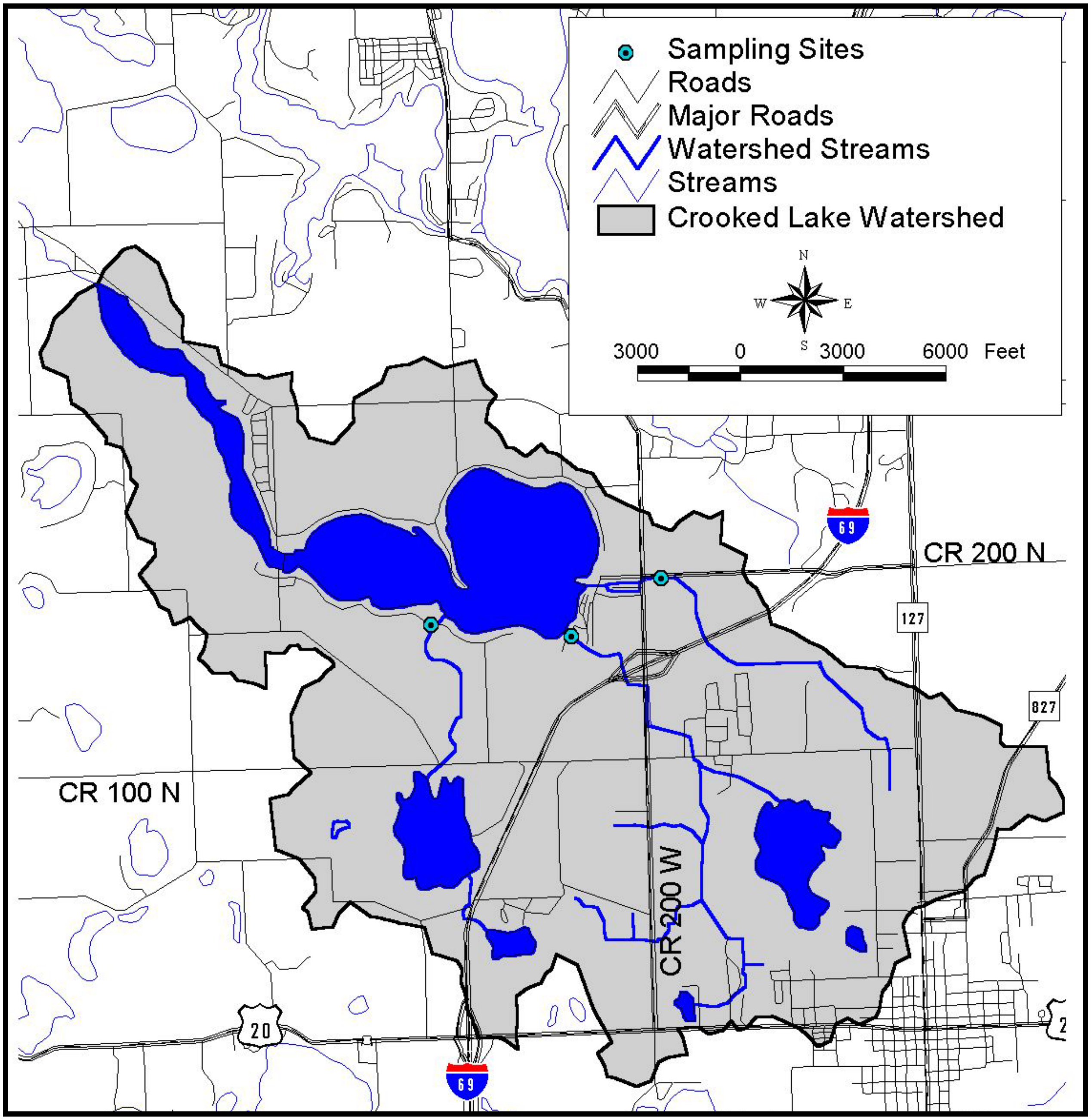

Figure 6. Sampling site locations in the Crooked Lake Watershed.

Collected samples were stored on ice and transported the same day as collection to EIS Analytical Laboratories in South Bend, Indiana. The water quality samples were analyzed for a variety of physical, biological, and chemical parameters. The following is a brief description of each of these parameters.

Temperature

Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. Likewise, water temperature regulates the species composition and activity of life associated with the aquatic environment. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (EPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits for Indiana streams. Temperatures should not exceed 21.1º C by more than 1.7 ºC during the month of April or exceed 26.7º C by 1.7 ºC during the month of May. (Water quality sample collection for this assessment occurred in these two months.) At no time should water temperatures exceed 32.2 ºC. In addition, the Indiana Administrative Code (IAC) states that "the maximum temperature rise at any time or place…shall not exceed 2.8 ºC in streams and 1.7 ºC in lakes and reservoirs."

Dissolved Oxygen

Dissolved oxygen (DO) is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 mg/l of DO. The IAC requires that all waterbodies possess a daily dissolved oxygen average concentration of at least 5 mg/l and that at no time shall the DO concentration drop below 4 mg/l. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth, accompanied by high levels of photosynthetic activity, can over-saturate (greater than 100% saturation) the water with DO. Dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

pH

The pH of water describes the concentration of acidic ions (specifically H+) present in water. The pH also determines the form, solubility, and toxicity of a wide range of other aqueous compounds. The IAC establishes a range of 6 to 9 pH units for the protection of aquatic life. pH concentrations in excess of 9 are acceptable only when occurring as daily fluctuations associated with photosynthetic activity.

Nutrients (Nitrogen and Phosphorus)

Nutrients are a necessary component of aquatic ecosystems. Ecosystem primary producers (i.e. plants) require nutrients for growth. Growth of the primary producers ultimately supports the remainder of the organisms in the ecosystem's food web. Insufficient nutrient levels in stream and lake water can limit the size and complexity of biological communities living in the stream or lake. In contrast, excessive levels of nutrients in lake or stream water alter biological communities by promoting nuisance species growth. For example, high concentrations of total phosphorus in lake water (>0.03 mg/l) create ideal conditions for nuisance algae growth. In extreme cases, lake algae growth can exclude rooted macrophyte growth and shift fish community composition.

In low order streams such as the unnamed tributaries to Crooked Lake, aquatic plants exist primarily as periphyton (algae attached to substrate or other surfaces in the stream). Light availability and flow regime limit the establishment of rooted macrophytes and phytoplankton populations that are more common in lakes and large river systems. As small stream ecosystems' primary producers, periphyton support higher members of the stream food web (invertebrates, fish). Nutrients are one of the factors that limit periphyton growth in streams and thus are included in stream water chemistry analyses.

Phosphorus and nitrogen are common nutrients governing plant growth. (When diatoms dominate the periphyton or planktonic community, silica is also an important nutrient.) Sources of phosphorus and nitrogen include fertilizers, human and animal waste, atmospheric deposition in rainwater, and yard waste or other plant material that reaches streams. Nitrogen can also diffuse from the air into streams. Atmospheric nitrogen is then “fixed” by certain algae species (cyanobacteria) into a usable form of nitrogen. Because of this readily available source of nitrogen (the air), phosphorus is usually the “limiting nutrient” in aquatic ecosystems.

Phosphorus and nitrogen exist in several forms in water. The two common phosphorus forms are soluble reactive phosphorus (SRP) and total phosphorus (TP). SRP is the dissolved form of phosphorus. It is the form that is “usable” by algae. Algae cannot directly digest and use particulate phosphorus for growth. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. Only TP was measured during this assessment. The most commonly measured nitrogen forms are nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), and total Kjeldahl nitrogen (TKN). Nitrate is a dissolved form of nitrogen that is commonly found in surface water where oxygen is readily available. In contrast, ammonia-nitrogen is generally found in water where oxygen is lacking. Ammonia-nitrogen, or more correctly the ionized form of ammonia-nitrogen (ammonium), is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the total organic nitrogen (particulate) and ammonia-nitrogen in the water sample.

Indiana possesses nitrate-nitrogen and ammonia-nitrogen standards for its water bodies. These standards apply to all state water bodies except those designated as Limited Use waters. The nitrate-nitrogen standard is 10 mg/l; nitrate-nitrogen concentrations exceeding 10 mg/l in drinking water are considered hazardous to human health (Indiana Administrative Code IAC 2-1-6). Because both temperature and pH govern the toxicity of ammonia for aquatic life, these factors are weighed in ammonia the standard. Depending on the temperature and pH range of the study streams maximum unionized ammonia-nitrogen concentrations should not exceed 2.5-13.1 mg/l.

Total suspended solids

Total suspended solids refer to all particles suspended or dissolved in stream water. Sediment, or dirt, is the most common solid suspended in stream water. The sediment in stream water originates from many sources, but a large portion of sediment entering streams comes from active construction sites or other disturbed areas such as unvegetated stream banks.

Suspended solids impact streams in a variety of ways. When suspended in the water column, solids can clog the gills of fish and invertebrates. As the sediment settles to the creek bottom, it covers spawning and resting habitat for aquatic fauna, reducing the animals’ reproductive success. Suspended sediments also impair the aesthetic and recreational value of a waterbody. In lakes and reservoirs, sediment accumulation limits boating opportunities and shortens the waterbody’s lifespan. Similarly, few people are enthusiastic about having a picnic near a muddy creek or wading in silty water. Pollutants attached to sediment also degrade water quality.

Pathogens
Bacteria, viruses, and other pathogens are contaminants of concern in both rural and urban watersheds. Common sources of these pathogens include human and wildlife waste, fertilizers containing manure, previously contaminated sediments, septic tank leachate, and illicit connections to stormwater sewers or drainage tiles. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. Thus, pathogens can impair the recreational value of a stream. Some pathogens can also impair biological communities. Water quality researchers and monitoring programs utilize *E. coli* as an indicator for the presence of pathogens in water. According to the Indiana Administrative Code, *E. coli* concentrations should not exceed 235 colonies/100 mL in any one sample within a 30-day period.

2.2.2 Water Quality Results and Discussion
There are two useful ways to report water quality data in flowing water. *Concentrations* express the mass of a substance per unit volume, for example milligrams of total suspended solids per liter (mg/l). *Mass loading* describes the mass of a particular material being carried per unit time (kg/d). Loading is important when comparing among sites and among sampling dates because: 1) Flow can be highly variable; therefore, normalizing concentrations to flow eliminates variability. 2) Delivery of materials is important to consider. For example, a stream with high discharge but low pollutant concentration may deliver more of a pollutant to its receiving body than a stream with a higher pollutant concentration but lower discharge. It is the total amount of nutrients, suspended solids, and pathogens entering the stream that is of greatest concern when considering the effects of these materials downstream.

Selected Physical and Chemical Parameter Concentrations
Table 8 presents results for physical and selected chemical parameters measured during base flow and storm flow.

Table 8. Selected physical and chemical parameter data collected from Crooked Lake Watershed sites.

Stream	Site	Date	Timing	Flow (cfs)	Temp (^oC)	DO (mg/L)	DO Sat (%)	pH (SU)
Loon Lake Tributary	1	4/28/03	base	no water	--	--	--	--
		5/1/03	storm	no water	--	--	--	--
Carpenter Drain	2	4/28/03	base	0.058	15.7	11.4	114.2	8.1
		5/1/03	storm	0.142	14.2	8.5	82.9	8.0
Palfreyman Drain	3	4/28/03	base	0.043	19.1	11.4	123.8	8.4
		5/1/03	storm	0.492	15.9	7.7	77.5	7.9

Values of temperature and pH in the Crooked Lake inlets were well within the ranges established by the Indiana Administrative Code for the protection of aquatic life. Temperatures measured within the Crooked Lake inlets varied from 14.2 ºC to 19.1 ºC. The highest temperatures were observed in Palfreyman Drain most likely due to the shallow nature of the stream and the lack of riparian vegetation along most of the drain's length. All temperatures measured in the Crooked Lake inlets were below the maximum temperature limit suitable to protect warmwater aquatic life.

Dissolved oxygen (DO) concentrations varied from 7.7 mg/l to 11.4 mg/l. Both Carpenter and Palfreyman Drain possessed dissolved oxygen concentrations of 11.4 during base flow; however, during storm flow dissolved oxygen concentrations in Palfreyman Drain were lower than those measured in Carpenter Drain. DO at all sites exceeded the Indiana state minimum standard of 5 mg/l indicating that oxygen was sufficient to support aquatic life during both storm and base flow sampling.

Since DO varies with temperature (cold water can hold more oxygen than warm water), it is also important to examine DO saturation values. DO saturation refers to the amount of DO dissolved in water compared to the total amount possible when equilibrium between the stream water and the atmosphere is maximized. When a stream is less than 100% saturated with oxygen, decomposition processes within the stream may be consuming oxygen more quickly than it can be replaced and/or flow in the stream is not turbulent enough to entrain sufficient oxygen. Oversaturation occurs when in-stream processes add more oxygen to the water column than would be expected at a given temperature. Carpenter Drain was 83-114% saturated with oxygen during both sampling events, while Palfreyman Drain was 78-124% saturated suggesting that both inlet streams are well oxygenated. The low saturation during storm flow is likely due to the two factors noted above: the consumption of oxygen during the decomposition of organic material in the stream and the relatively non-turbulent water limiting the entrainment of oxygen into the stream from the air. Supersaturation observed at Palfreyman Drain during base flow is likely the result of algal growth in response to high nutrient concentrations; supersaturation at Carpenter Drain is likely due to both moderately turbulent flow and algal growth.

Chemical and Bacterial Parameter Concentrations

Table 9 lists the chemical and bacterial concentration data for the Crooked Lake inlets by site.

Table 9. Nutrient, sediment, and bacterial parameter data from the Crooked Lake watershed sites.

Site	Date	Timing	NO_3-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)	TP (mg/l)	TSS (mg/l)	*E. coli* (col/100ml)
1	4/28/03	base	--	--	--	--	--	--
	5/1/03	storm	--	--	--	--	--	--
2	4/28/03	base	1.1	0.1	1.4	0.05*	2	8
	5/1/03	storm	1.7	0.4	1.0	0.05*	1*	120
3	4/28/03	base	0.22	0.05*	1.2	0.05*	3	25
	5/1/03	storm	0.44	0.05*	1.2	0.05*	1*	180

*Method detection level.

Nitrate-nitrogen concentrations during base and storm flow conditions were relatively low at both sites. Base flow concentrations ranged from 0.22 mg/l in Palfreyman Drain to 1.1 mg/l in Carpenter Drain, while storm flow nitrate-nitrogen concentrations ranged from 0.44 mg/l in Palfreyman Drain to 1.7 mg/l in Carpenter Drain. Nitrate-nitrogen concentrations in Palfreyman Drain were close to or lower than the U.S. Environmental Protection Agency (USEPA) recommended nitrate-nitrogen level (0.30 mg/l) for streams in the Nutrient Ecoregion VII, which includes the Crooked Lake Watershed (USEPA, 2000). However, nitrate-nitrogen concentrations in Carpenter Drain exceeded the median nutrient concentrations observed in Ohio streams (1.0 mg/l) known to support healthy warmwater habitats for aquatic life (Ohio EPA, 1999). Concentrations at both sites were well below 10 mg/L, the concentration set by the Indiana Administrative Code for safe drinking water.

Ammonia-nitrogen concentrations were similarly low at both sites during base and storm flow sampling. The storm flow sample collected at Carpenter Drain exhibited the highest ammonia-nitrogen concentration (0.4 mg/l), while base and storm flow samples collected from Palfreyman Drain possessed concentrations below the detection limit (0.05 mg/l). Only one site, Carpenter Drain during storm flow, exceeded the IAC standard. The elevated ammonia-nitrogen concentration coupled with the low dissolved oxygen concentration suggests decomposition of organic matter is occurring in this stream.

In general, total Kjeldahl nitrogen, total phosphorus, and total suspended solids concentrations were low in the inlets to Crooked Lake. TKN levels exceeded USEPA recommended concentrations; however, these TKN concentrations are typical of Indiana streams. Total phosphorus and total suspended solids concentrations were at or below detection level during both base and storm flow sampling. Total suspended solids concentrations measured during base flow sampling exceeded concentrations measured in storm flow samples at both sample sites.

The storm flow sample collected in Palfreyman Drain possessed the highest *E. coli* concentration (180 colonies/100 ml), while the base flow sample from Carpenter Drain exhibited the lowest *E. coli* concentration (8 colonies/100 ml). None of the samples collected during base or storm flow exhibited *E. coli* concentrations above the state standard (235 colonies/100 ml). *E. coli* concentrations in the Crooked Lake inlets were much lower than other streams in the state. White (unpublished) found the average *E. coli* concentration in Indiana streams to be approximately 650 colonies/100 ml; the average *E. coli* concentrations measured in the Crooked Lake inlets was 83 colonies/100 ml.

Nutrient and Sediment Parameter Mass Loading
Table 10 lists the nutrient and sediment mass loading data in the Crooked Lake inlets.

Table 10. Chemical and sediment loading data from Crooked Lake inlets.

Site	Date	Timing	NO_3-N Load (g/d)	NH_3-N Load (g/d)	TKN Load (g/d)	TP Load (g/d)	TSS Load (g/d)
1	4/28/03	base	--	--	--	--	--
	5/1/03	storm	--	--	--	--	--
2	4/28/03	base	6	0.5	7	bdl	10
	5/1/03	storm	12	5	12	bdl	bdl
3	4/28/03	base	5	bdl	5	bdl	11
	5/1/03	storm	19	bdl	51	bdl	43

bdl=below detection level

Under base flow conditions, Carpenter Drain exhibited a higher loading rate for nitrate-nitrogen, ammonia-nitrogen, and total Kjeldahl nitrogen compared to that measured in Palfreyman Drain. This is to be expected. Carpenter Drain possesses a larger watershed therefore; it generally receives more pollutants than Palfreyman Drain. In contrast, Palfreyman Drain exhibited a slightly higher load rate for total suspended solids than that present in Carpenter Drain. The slight elevation observed in Palfreyman Drain may be due to sediment loss from agricultural fields immediately upstream of the sampling site. Watershed size is typically directly proportional to pollutant loading rates; large watersheds often discharge more pollutants than smaller watersheds to their adjacent streams and the streams often possess greater flow rates, thereby increasing pollutant loading rates (pollutant loading rate = pollutant concentration x flow rate).

Under storm flow conditions, Palfreyman Drain possessed higher total Kjeldahl nitrogen and total suspended solids concentrations. Again, these observations are consistent with expectations. The predominance of impervious surfaces in the headwaters of Palfreyman Drain funnels storm water out of parking lots and off of roads into storm drains and drainage ditches. Extensive wetland complexes located along the headwaters of Carpenter Drain store stormwater releasing water downstream at similar flow rates during both base and storm flow conditions. Percent of impervious surface is often directly proportional to pollutant loading rates following storm events; watersheds possessing larger percentages of roads, parking lots, and buildings often discharge more water and pollutants than watersheds possessing more open, permeable areas. Following storm events, the streams often possess greater flow rates, which results in greater pollutant loading rates.

2.3 Summary and Conclusions

Stream chemistry samples collected during 2003 at the Crooked Lake inlets indicate that the streams possess moderately good water quality. Generally, Carpenter Drain possessed poorer water quality than Palfreyman Drain. However, the greater the discharge in Palfreyman Drain following a storm event led to higher nutrient and sediment loading rates. Collectively, the data indicate that Crooked Lake inlet water quality is conducive for supporting aquatic life. Nutrient and sediment concentrations measured during 2003 were much lower than those measured during the Steuben County Health Department sampling (1973-1977) and the sampling conducted by William W. Hill and Associates (1988).

3.0 WATERSHED INVESTIGATION

3.1 Introduction

Targeting areas of concern and selecting sites for future management are the goals of a visual watershed inspection. A walking tour of the two major drains to Crooked Lake, Palfreyman and Carpenter Drains, was conducted in March 2003. A windshield survey of the Crooked Lake Watershed was conducted in conjunction with the walking tour in March 2003.

3.2 Sites for Potential Management Practice Implementation

Most observations made during the walking tour and windshield survey relate to the need for best management practice (BMP) implementation. Table 11 lists all sites where BMP implementation or installation could benefit water quality. Site locations are displayed by subwatershed in Figures 7 to 9. Figure 10 combines Figures 7 to 9 showing the entire Crooked Lake Watershed at once and representative photos appear in Figures 11 to 18.

Table 11. List of locations where the application of best management practices would improve water quality in the Crooked Lake Watershed as observed during the walking tour and windshield survey. The issues of concern and practices that could be used to treat the concern(s) are also listed.

Site	Identified Concern	Potential Management Practice
P1	Road drainage/litter	Re-route water from road drainage into vegetated swale; initiate roadside litter clean-up program along tributaries
P2	Pipe draining county highway facility; truck in parking lot leaking petroleum based substance to drain	Work with the county highway department to address storage of materials and vehicle; route parking lot drainage through vegetated swale or off-line detention
P3	Road drainage/litter	Re-route water from road drainage into vegetated swale; initiate roadside litter clean-up program along tributaries
P4	Field is farmed to stream edge	Utilize conservation tillage and/or install filter strips
P5	Streambank erosion	Feasibility/design project*
P6	I-69 drainage pipe	Explore filtering options
P7	Sediment deposition along stream bed	Feasibility/design project*
P8	Streambank erosion (Figure 11)	Feasibility/design project*
P9	Field is farmed to stream edge	Utilize conservation tillage and/or install filter strips
P10	Residential area drainage pipe	Explore filtering options
P11	Sediment deposition along stream bed	Feasibility/design project*
P12	Streambank erosion (Figure 12)	Feasibility/design project*

P13	Factory drainage basin overflow pipe	Explore filtering options
P14	Drainage tile outlet pipe	Explore filtering options
P15	Streambank erosion	Feasibility/design project*
P16	Streambank erosion (Figure 13)	Feasibility/design project*
P17	Streambank erosion	Feasibility/design project*
P18	Historic wetland	Potential wetland restoration site
P19	Streambank erosion	Feasibility/design project*
P20	Streambank erosion	Feasibility/design project*
P21	Residential area drainage pipe	Explore filtering options
P22	Residential area drainage pipe	Explore filtering options
P23	Drainage tile outlet pipe	Explore filtering options
P24	Angola storm sewer system drain pipe	Explore filtering options
P25	Angola storm sewer system drain pipe	Explore filtering options
P26	Angola storm sewer system drain pipe	Explore filtering options
P27	Angola storm sewer system drain pipe	Explore filtering options
P28	Angola storm sewer system drain pipe	Explore filtering options
P29	Angola storm sewer system drain pipe	Explore filtering options
P30	Invasive species growing outside of shopping center drainage basin	Work with the shopping center manager to remove and/or contain invasive species.
P31	Angola storm sewer system drain pipe	Explore filtering options
P32	Angola storm sewer system drain pipe	Explore filtering options
P33	Water is by-passing storm drains and causing erosion (Figure 14)	Work with the City Engineer to address storm drain issues
P34	Harcourt Road extension; bare sediment	Work with the City and County Engineers to implement storm water runoff control measures
C1	Streambank erosion (Figure 15)	Feasibility/design project*
C2	Old drainage pipe in stream channel; streambank erosion (Figure 16)	Remove drainage pipe; feasibility/design project*
C3	I-69 drainage pipe	Explore filtering options
C4	Road drainage/litter (Figure 17)	Re-route water from road drainage into vegetated swale; initiate roadside litter clean-up program along tributaries
C5	I-69 curb and gutter drainage system in disrepair	Work with the Indiana Department of Transportation (INDOT) to repair and/or replace current drainage system
C6	Historic wetland (Figure 18)	Potential wetland restoration site
C7	Road drainage/litter	Re-route water from road drainage into vegetated swale; initiate roadside litter clean-up program along tributaries
C8	Historic wetland	Potential wetland restoration site
C9	Residential area drainage pipe	Explore filtering options
C10	Historic wetland	Potential wetland restoration site
C11	Historic wetland	Potential wetland restoration site
C12	Historic wetland	Potential wetland restoration site

C13	Historic wetland	Potential wetland restoration site
L1	Historic wetland	Potential wetland restoration site

*There are various alternatives to treat this problem. Alternatives should be explored in a feasibility study.

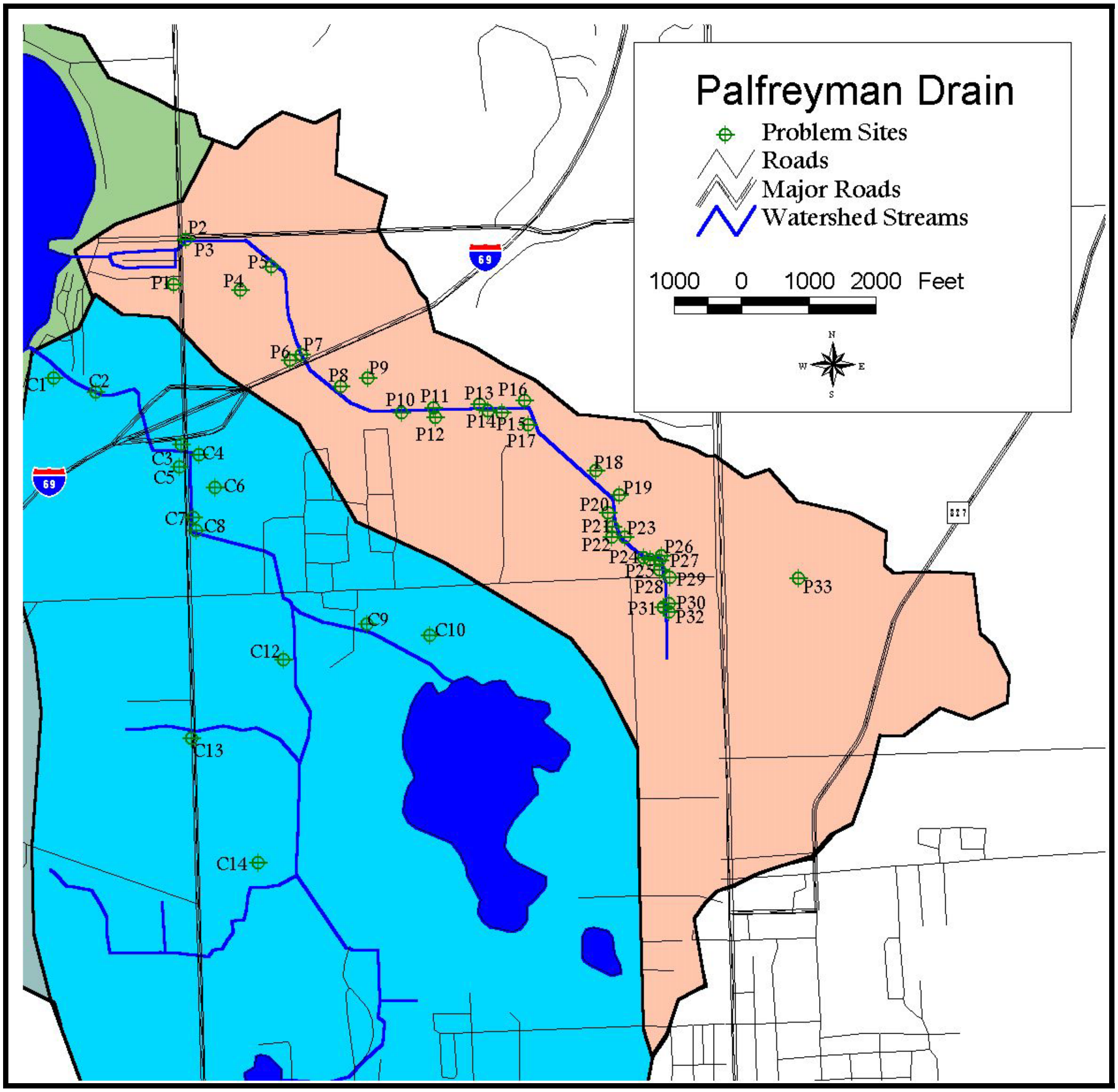

Figure 7. Problem sites identified in the Palfreyman Drain subwatershed during the walking tour and windshield survey conducted during March 2003.

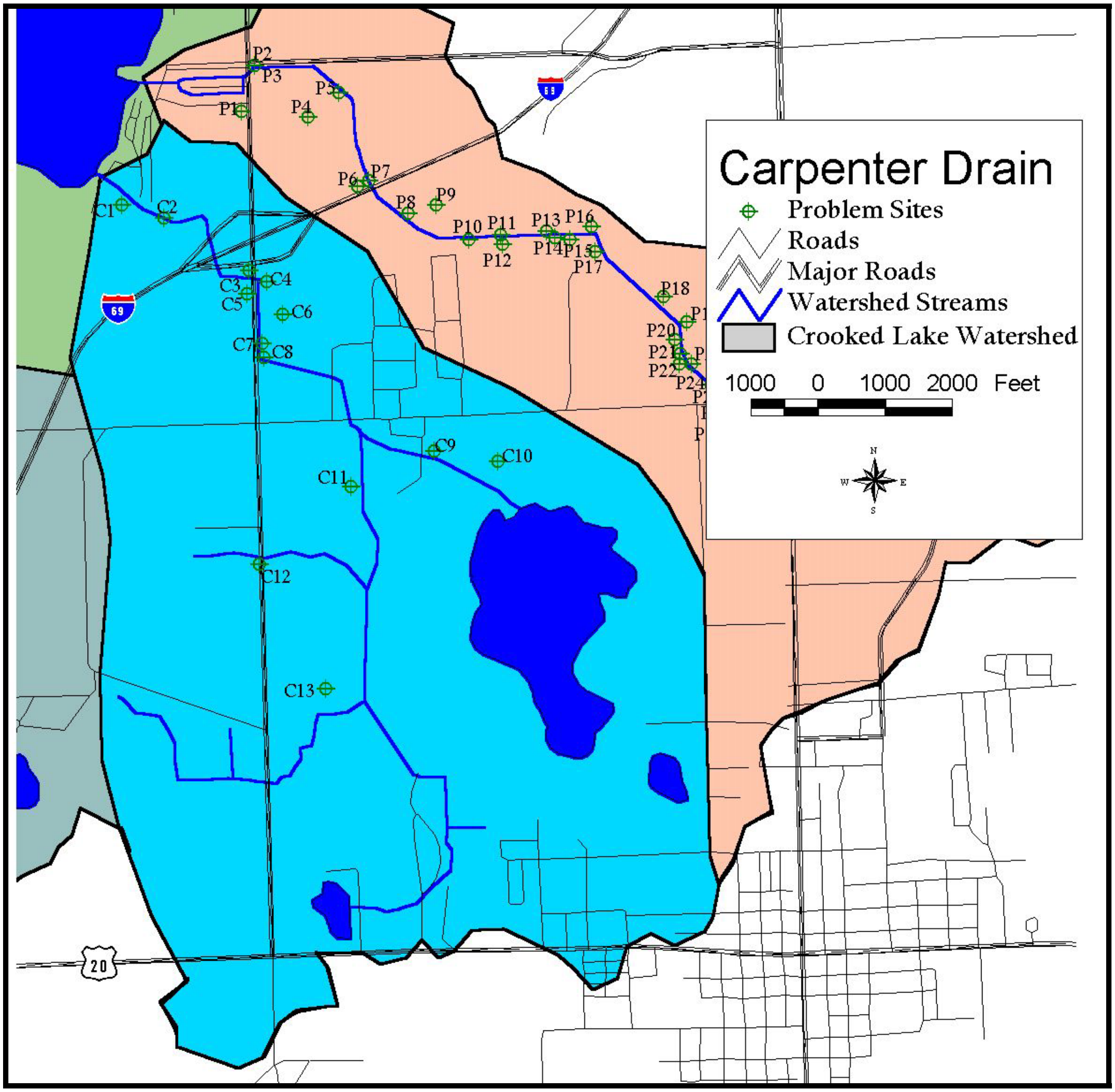

Figure 8. Problem sites identified in the Carpenter Drain subwatershed during the walking tour and windshield survey conducted during March 2003.

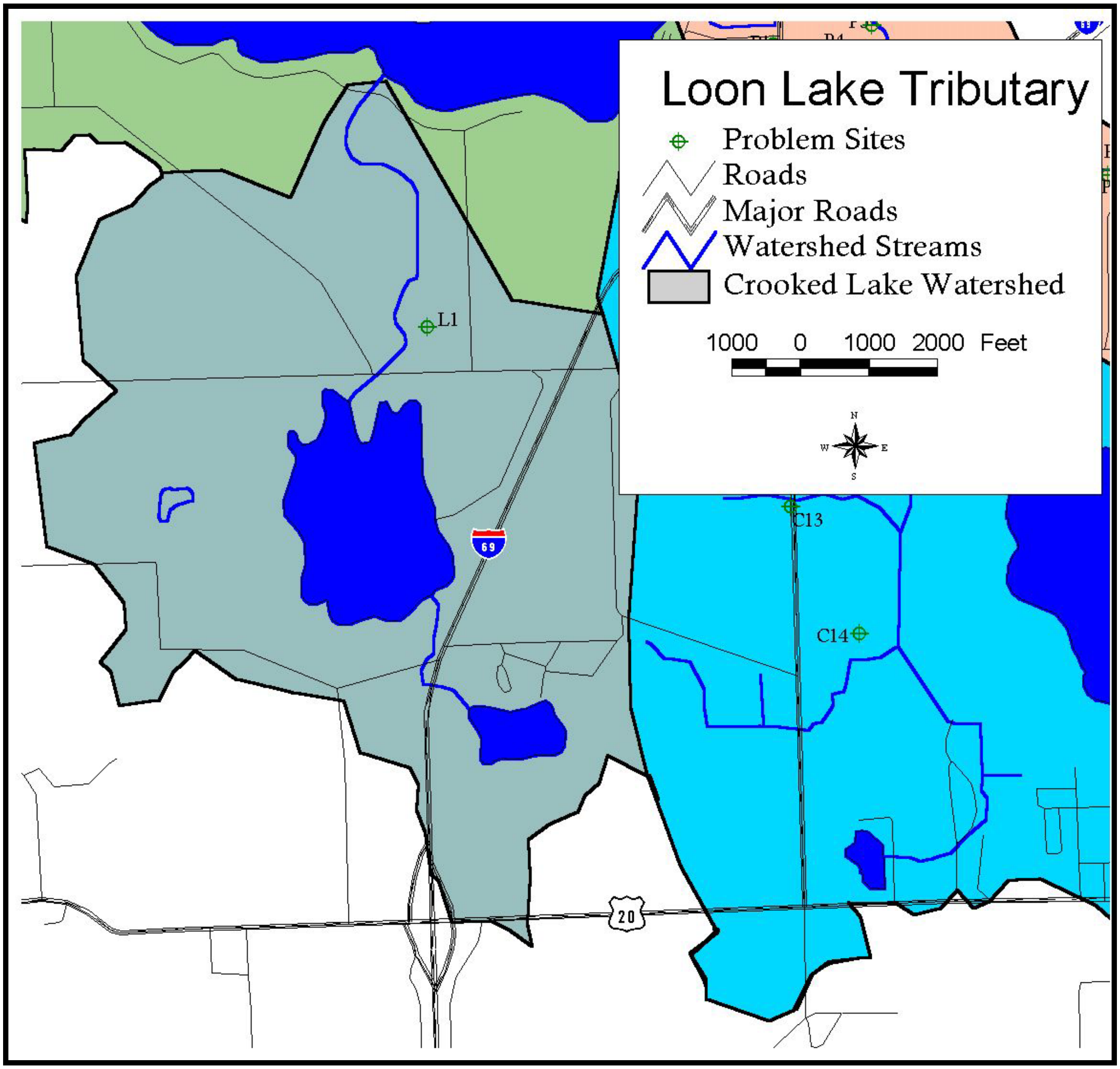

Figure 9. Problem sites identified in the Loon Lake Tributary subwatershed during the walking tour and windshield survey conducted during March 2003.

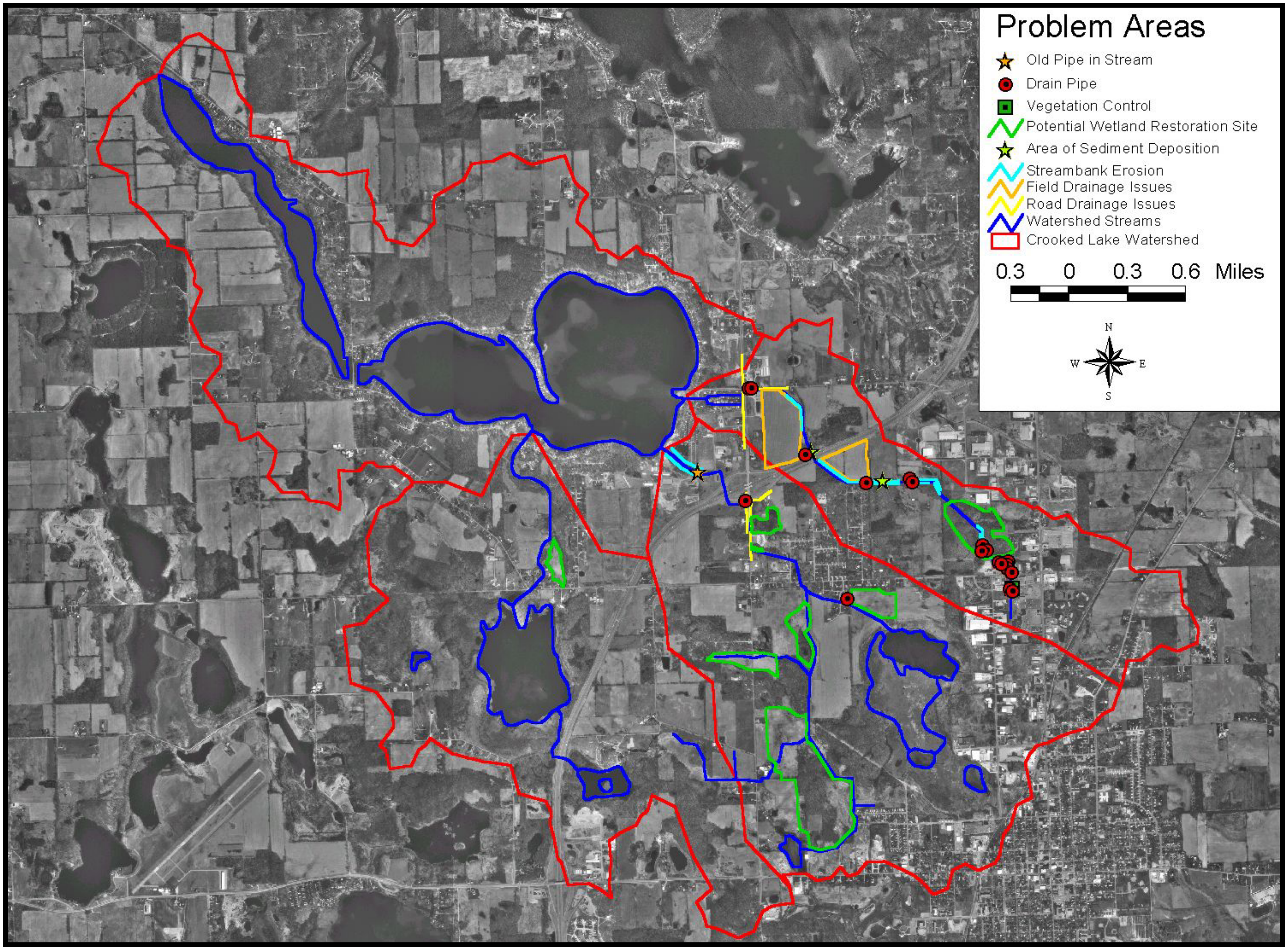

Figure 10. Problem sites and management recommendations identified during the walking tour and windshield survey conducted during March 2003.

Figure 11. Sediment deposition and streambank erosion observed along Palfreyman Drain at site P8.

Figure 12. Site P12 showing streambank erosion along Palfreyman Drain.

Figure 13. Site P16 showing sloughing banks along Palfreyman Drain.

Figure 14. Water by-pass of existing stormwater infrastructure observed at Site P33.

Figure 15. Site C1 showing streambank erosion along Carpenter Drain near the outlet to Crooked Lake.

Figure 16. Site C2 showing an old drainage pipe causing water deflection which results in streambank erosion and bank sloughing along Carpenter Drain.

Figure 17. Site C4 showing litter and the lack of road drainage filtration along Carpenter Drain at County Road 200 West.

Figure 18. Potential wetland restoration site located adjacent to Carpenter Drain at Site C6.

4.0 RECOMMENDATIONS

Below is a summary list of management recommendations for the Crooked Lake Watershed.

1. Work with the County Highway Department to address storage of materials and vehicles on the county lot at the intersection of County Road 200 West and County Road 200 North. Re-route drainage from the parking lot through a vegetated swale or offline detention basin to reduce sediment, nutrient, and petroleum product loading to Palfreyman Drain and Crooked Lake.

2. Implement bank and channel erosion control techniques along Palfreyman Drain from County Road 200 North south to the sediment trap and from I-69 southeast to County Road 100 North to stabilize the channel and reduce sediment and nutrient loading to Crooked Lake.

3. Work with the Soil and Water Conservation District (SWCD) office, the surveyor's office, and landowners to place agricultural land in the Conservation Reserve Program where possible or utilize conservation tillage methods in the Palfreyman Drain subwatershed. Work with the SWCD to restore wetlands along the upper portion of the drain.

4. Work with the city and county engineers to implement storm water runoff control measures in the headwaters of Palfreyman Drain (Heman Carpenter Drain and Charles Sheets Drain) to reduce sediment and nutrient loading to Crooked Lake.

5. Implement bank and channel erosion control techniques along the lower portion of Carpenter Drain to stabilize the channel and reduce sediment and nutrient loading to Crooked Lake.

6. Work with the Soil and Water Conservation District (SWCD) office, the surveyor's office, and landowners to restore wetlands in the Carpenter Drain Subwatershed. (See Figure 8 for specific locations.)

7. Work with the Soil and Water Conservation District (SWCD) office, the surveyor's office, and landowners to restore wetlands in the Loon Lake Tributary Subwatershed. (See Figure 9 for specific locations.)

8. Work with the County Highway Department and the surveyor's office to re-route water from road drainage along County Road 200 West and I-69 entrance and exit ramps into vegetated swales or off-line detention areas to reduce sediment and nutrient loading to Crooked Lake. Explore the possibility of constructing biofilters or filtration systems to treat roadside runoff.

9. Institute an Adopt-A-Road campaign along County Road 200 West from County Road 100 North to County 200 North to remove trash and roadside debris.

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